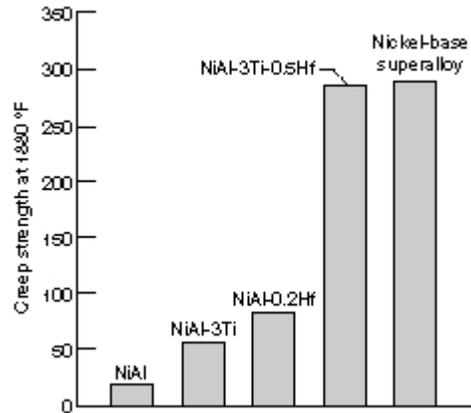


Development of Creep-Resistant NiAl(Ti,Hf) Single-Crystal Alloys

Nickel-base superalloys are the current choice for high-temperature jet engine applications such as turbine blades and vanes. However, after more than five decades of use, nickel-base superalloys have reached their limit, since the operating temperatures in gas turbine engines are now approaching the melting temperature of these alloys. Thus alternative materials, such as lightweight NiAl intermetallic alloys with superior properties, (e.g., high melting temperature, high thermal conductivity, and excellent chemical stability and oxidation resistance) are required for the next generation of high-temperature structural materials for more efficient 21st century civil transport systems.

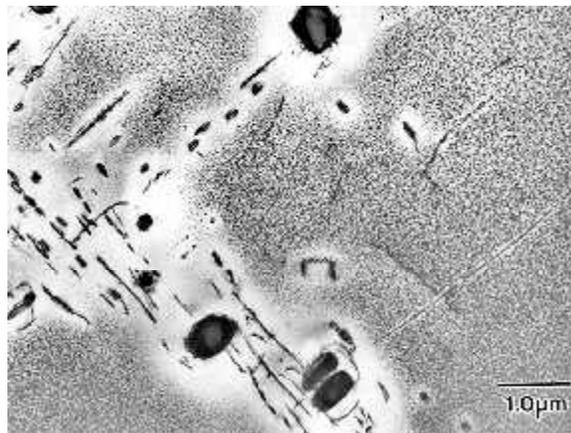
The two major disadvantages that have historically prevented the application of NiAl as a high-temperature structural material are its poor creep resistance and low room-temperature ductility. Alloying strategies similar to those used for nickel-base superalloys are being used to improve the high-temperature strength via solid-solution and precipitate-hardening effects. This study highlights the potent role of Ti and Hf as potential solid-solution strengtheners in NiAl and also the added effect of second-phase particles when Ti and Hf are both used.

The high-temperature deformation behavior of $\langle 001 \rangle$ NiAl-3Ti, NiAl-0.2Hf, and NiAl-3Ti-0.5Hf (at.%) single crystals was studied at the NASA Lewis Research Center in the temperature range ~ 800 to 1150 °C. The bar graph shows steady-state creep strengths of these alloys at 1027 °C (1880 °F) at a strain rate of $\sim 10^{-6}$ sec $^{-1}$. Comparison of these alloys with unalloyed NiAl and a first-generation single-crystal superalloy shows that the strengths of the NiAl alloys are higher than those of binary NiAl and that they approach that of the superalloy. This increase in strength (to that of the superalloy) was accomplished with total alloying additions of less than four atomic percent. Furthermore, because the NiAl-3Ti-0.5Hf alloy is much lighter than the superalloy, it would exhibit about a 30-percent greater density-compensated creep strength in comparison to the superalloy under the test conditions described in the bar graph.



Creep strength comparison of binary NiAl, alloyed NiAl single crystals, and a first-generation single-crystal nickel-base superalloy made at 1880 °F and a strain rate of $1 \times 10^{-6} \text{ sec}^{-1}$.

Transmission electron microscopy observations showed essentially no precipitation in the NiAl-3Ti and NiAl-0.2Hf alloys. Additional analysis revealed that strengthening in these alloys is due solely to solid-solution effects through a significant increase in the drag force on dislocations. When both Hf and Ti are added to the alloy, the individual solubility for each element decreases, resulting in significant precipitation. Consequently, the NiAl-3Ti-0.5Hf alloy contained a high density of very fine Heusler (Ni_2AlTi) precipitates and a lower density of heterogeneously nucleated and somewhat coarser Heusler ($\text{Ni}_2\text{Al}(\text{Hf},\text{Ti})$) precipitates within the NiAl matrix, as shown in the photomicrograph. A higher level of strength was achieved in this precipitate-containing alloy because of the combined strengthening effects associated with solute drag on the dislocations plus impedance due to the presence of precipitate particles. The strength level of this alloy approaches that of the superalloy single crystal, whereas even higher levels of these alloying additions would increase the amount of precipitate phase and the strength of the NiAl even further.



Microstructure of a creep-resistant NiAl-3Ti-0.5Hf single-crystal alloy.

Consequently, through combined solid-solution and precipitation-strengthening mechanisms, NiAl alloys can be developed with creep strengths equivalent or superior to conventional nickel-base superalloys, while at the same time providing a 33-percent weight savings and higher temperature capability.

Lewis contacts: Dr. Ronald D. Noebe, (216) 433-2093, Ronald.D.Noebe@grc.nasa.gov;
Dr. Anita Garg, (216) 433-8908, Anita.Garg@grc.nasa.gov; and Dr. J. Daniel
Whittenberger, (216) 433-3196, jdwhittenberger@grc.nasa.gov

Author: Dr. Ronald D. Noebe

Headquarters Program Office: OA